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FINAL REPORT

FINITE DIFFERENCE TIME DOMAIN ELECTROMAGNETIC SCATTERING FROM FREQUENCY-DEPENDENT LOSSY MATERIALS

Under Contract NAG 2-~~684~~ ~~648~~ 867
NASA Ames Research Center

Submitted to

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INTRODUCTION

This final report summarizes the research accomplishments under Contract NAG 2-648 between NASA Ames Research Center and the Pennsylvania State University. More specific information on each topic covered in this report is contained in the manuals and preprints which have been submitted along with this report, as described in the Deliverables section of the Statement of Work for the subject contract. Also submitted with this report are 4 different FDTD computer codes and companion RCS conversion codes on magnetic media. In the remainder of this report the preprints, the computer codes and their user's manuals will be summarized.

COMPUTER CODES DELIVERED

Under this effort a single three dimensional dispersive FDTD code for both dispersive dielectric and magnetic materials was to be developed and delivered, along with a User's Manual. This code is included with this report on Magnetic Media, and is named "FDTDD", standing for the "D" version of a set of three-dimensional FDTD codes developed at Penn State. This code has the capability to calculate electromagnetic field interactions with objects which include both dispersive and non-dispersive dielectric and magnetic materials. Using a companion code, "RCS3D", the output from FDTDD can be converted to radar cross section vs frequency. A User's Manual describing the theory and use of the computer code FDTDD and showing validation results is included with this final report as attachment [1].

In addition to FDTDD, simpler (and somewhat faster) three-dimensional FDTD codes which have more limited or no dispersive material capability, "FDTDA" through "FDTDC", are also being delivered along with this final report. Version "A" is for frequency-independent materials, version "B" for frequency-dependent dielectric (non-magnetic) materials, and version "C" for frequency-independent dielectric and magnetic materials. While version "D" includes all of these cases, the simpler versions "A" through "C" are somewhat easier to use and will run faster than the more complicated "D" version. They are therefore preferred when the more extensive capabilities of the "D" version are not needed. All versions use the same "RCS3D" companion computer code to convert time domain output to RCS vs frequency. The User's Manuals for all four versions of the Penn State FDTD code are included with this report as attachments [1-4].

While three-dimensional FDTD codes are generally more useful, two-dimensional codes can be applied to geometries of interest, and have the advantage of requiring significantly less computer resources. A pair of two-dimensional FDTD codes, "TEA" and "TMA", for transverse electric and transverse magnetic excitation, respectively, are also included with this final report on magnetic media. Also included are companion computer codes "SWTEA" and "SWTMA", which convert the time domain output of "TEA" and

"TMA" to scattering width vs frequency. The user's manual for these codes is also included with this report as an attachment [5]. A theoretical description and validation results for the two-dimensional computer codes are contained in a preprint included with this report as attachment [6].

EXTENSIONS TO DISPERSIVE FDTD CAPABILITIES

During this effort two extensions to our dispersive material FDTD capability were made. One was the extension to include magnetic materials which have more complicated frequency dependence of their permittivity than considered previously. The time domain magnetic susceptibility has the form of a damped sinusoidal wave, resulting from the oscillations of the microscopic currents in the material. Dispersive FDTD was extended to include this class of materials, and these results are reported in a PhD dissertation by Forrest Hunsberger that is included with this final report as attachment [7]. Some of this material has already been presented at the recent IEEE AP-S conference [8], and Dr. Hunsberger is currently writing papers based on this dissertation for journal submission.

The other extension is to a time domain surface "impedance" formulation for lossy conductors. As explained in attachment [9], this removes a difficulty in applying FDTD to targets containing lossy materials. The difficulty is due to the necessity of reducing the size of the FDTD cells which are inside the conducting materials. With the FDTD surface "impedance" described in [9], FDTD cells need not be located inside the conducting material but only at the surface. The attachment [9] preprint has already been accepted for publication in IEEE Trans. on Antennas and Propagation. These results have in part been presented at the recent IEEE AP-S symposium [10].

The approach used in [9] also extends the basic frequency dependent FDTD to a wider class of materials. This is due to the method used in [9] to obtain the necessary time domain convolution coefficients. With this method ANY material whose frequency dependent behavior is known can have this information be transformed to the time domain, and then with application of Prony's method (see [9]) the necessary exponential coefficients for applying dispersive FDTD can be obtained.

PLATE SCATTERING

During the course of this research effort three different plate scattering geometries were given special consideration. The first of these was suggested by Dr. Randy Jost. It involved a conducting plate coated with a dielectric layer. This geometry cannot readily be modeled using other scattering calculation methods. Scattering results for this geometry were calculated using one of our FDTD codes (the "FDTDA" code furnished under this effort). The results were documented and are attached to this report [11]. The results were previously furnished to Dr. Jost, and according to Dr. Jost they showed significant correlation with measurements. We hope to continue this investigation.

The second plate geometry considered was the "business card" plate geometry being used as a test case by Dr. Alex Woo of NASA Ames. This geometry is challenging since edge waves contribute to the scattering. Moment Method codes require approximately 10 times the usual density of modes to accurately compute the scattering from this geometry. Our results, shown in attachment [12] of this report, shown the difference in RCS computed using FDTD and a Moment Method code. Dr. Woo indicated that our results were quite accurate, considering that we used only 10 cells per wavelength running on a 486 PC. We hope to run this data again using more cells per wavelength, and compare our results directly with measurements.

The third topic considered was extending FDTD to include modeling of thin impedance sheets. While applicable to arbitrary shapes and in both two and three dimensions, the extension was validated by calculating RCS from thin flat impedance sheet plates. The results are reported in attachment [13].

NONLINEAR MATERIALS

Having extended the FDTD method to dispersive materials, another class of materials which it would be desirable to include are nonlinear materials. During this effort the current flowing in a wire antenna loaded with a nonlinear diode was successfully computed using FDTD. The results are shown in the attached preprint [14]. With this capability RCS from scatters including nonlinear loads or bulk materials may be computed using FDTD. Further extensions could include scattering of short pulses from nonlinear dispersive materials including ferrite absorbers.

WIRE ANTENNAS

The accuracy available from the FDTD method was demonstrated by computing the self impedance of a wire dipole antenna and the mutual impedance between two wire antennas. These results are reported in attachment [15].

CONCLUSIONS

During this effort the tasks specified in the Statement of Work have been successfully completed. The extension of FDTD to more complicated materials has been made. A three-dimensional FDTD code capable of modeling interactions with both dispersive dielectric and magnetic materials has been written, validated, and documented. This code is efficient and is capable of modeling interesting targets using a modest computer work station platform.

However, in addition to the tasks in the Statement of Work, a significant number of other FDTD extensions and calculations have been made. RCS results for two different plate geometries have been reported. The FDTD method has been extended to computing far zone time domain results in two dimensions. Finally, the capability to model nonlinear materials has been incorporated into FDTD and validated.

The FDTD computer codes developed have been supplied, along with documentation, and preprints describing the other FDTD advances have been included with this report as attachments.

ATTACHMENTS AND REFERENCES

1. John Beggs and Raymond Luebbers, "User's Manual for Three-Dimensional FDTD Version "D" Code for Scattering from Frequency-Dependent Dielectric and Magnetic Materials," July 1991.

2. John Beggs and Raymond Luebbers, "User's Manual for Three-Dimensional FDTD Version "A" Code for Scattering from Frequency-Independent Dielectric Materials," July 1991.

3. John Beggs and Raymond Luebbers, "User's Manual for Three-Dimensional FDTD Version "B" Code for Scattering from Frequency-Dependent Dielectric and Magnetic Materials," July 1991.

4. John Beggs and Raymond Luebbers, "User's Manual for Three-Dimensional FDTD Version "C" Code for Scattering from Frequency-Independent Dielectric Materials," July 1991.

5. John Beggs and Raymond Luebbers, "User's Manual for Two-Dimensional FDTD Version "A" Codes for TE and TM Scattering from Frequency-Independent Dielectric Materials," July 1991.

6. Raymond Luebbers, Deirdre Ryan, and John Beggs, "A Two-Dimensional Time Domain Near Zone to Far Zone Transformation," submitted to IEEE Transaction on Antennas and Propagation, May 1991.

7. Forrest Hunsberger, Jr., "Extension of the Finite Difference Time Domain Method to Gyrotropic Media," PhD Dissertation, The Pennsylvania State University, May 1991.

8. F. Hunsberger, R. Luebbers, K. Kunz, "Transient Analysis of Magnetoactive Plasma using Finite Difference Time Domain Method," IEEE Antennas and Propagation Society International Symposium, London, Ontario, Canada, June 24-28, 1991.

9. John Beggs, Raymond Luebbers, Kane Yee, and Karl Kunz, "Wideband Finite Difference Time Domain Implementation of Surface Impedance Boundary Conditions for Good Conductors," accepted for publication in IEEE Trans. on Antennas and Propagat.

10. J. Beggs, R. Luebbers, K. Kunz, K. Yee, "Wideband Finite Difference Time Domain Implementation of Surface Impedance Boundary Conditions for Good Conductors," IEEE Antennas and Propagation Society International Symposium, London, Ontario, Canada, June 24-28, 1991.

11. Raymond Luebbers and John Beggs, "Time Domain Scattering and Radar Cross Section Calculations for a Thin, Perfectly Conducting Plate," February 1991.

12. Raymond Luebbers and John Beggs, "Conical Cut Radar Cross Section Calculations for a Thin, Perfectly Conducting Plate," March 1991.

13. Raymond Luebbers and Karl Kunz, "FDTD Modeling of Thin Impedance Sheets," submitted to IEEE Trans. Antennas and Propagation, June 1991.

14. Raymond Luebbers, John Beggs, and Karl Kunz, "Finite Difference Time Domain Calculation of Transients in Antennas with Nonlinear Loads," submitted to IEEE Trans. Antennas and Propagation, July 1991.

15. Raymond Luebbers and Karl Kunz, "Finite Difference Time Domain Calculations of Antenna Mutual Coupling," submitted to IEEE Trans. on Electromagnetic Compatibility, April 1991.